Measurements of W+jets and Z+jets production cross sections at CDF

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On behalf of the CDF collaborations

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Outline

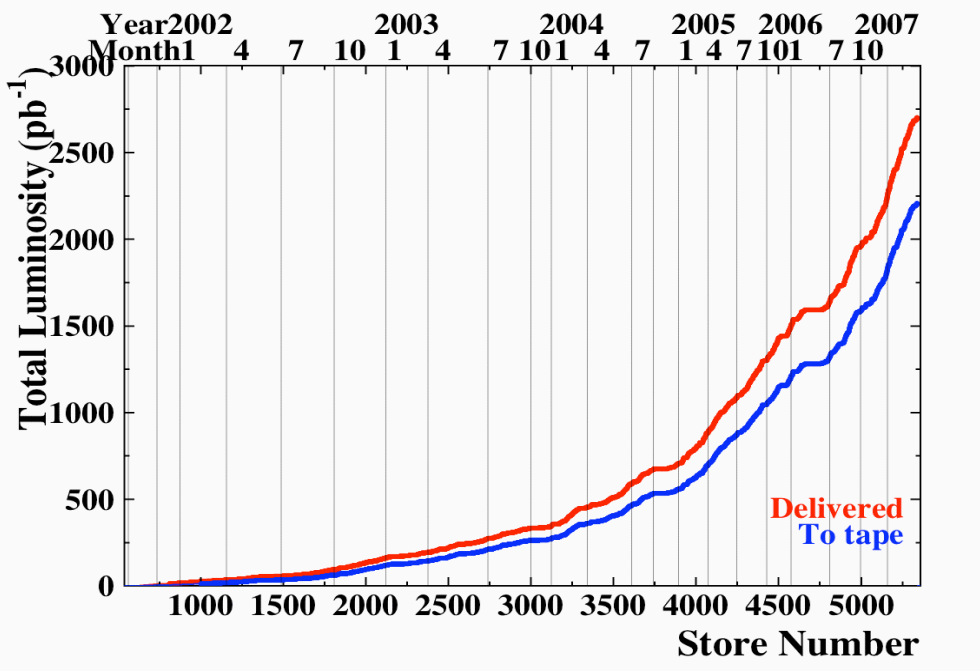
- The Tevatron and the CDF experiment
- Boson + jets @ the Tevatron
- Results on W/Z + jets
- Summary and Conclusions

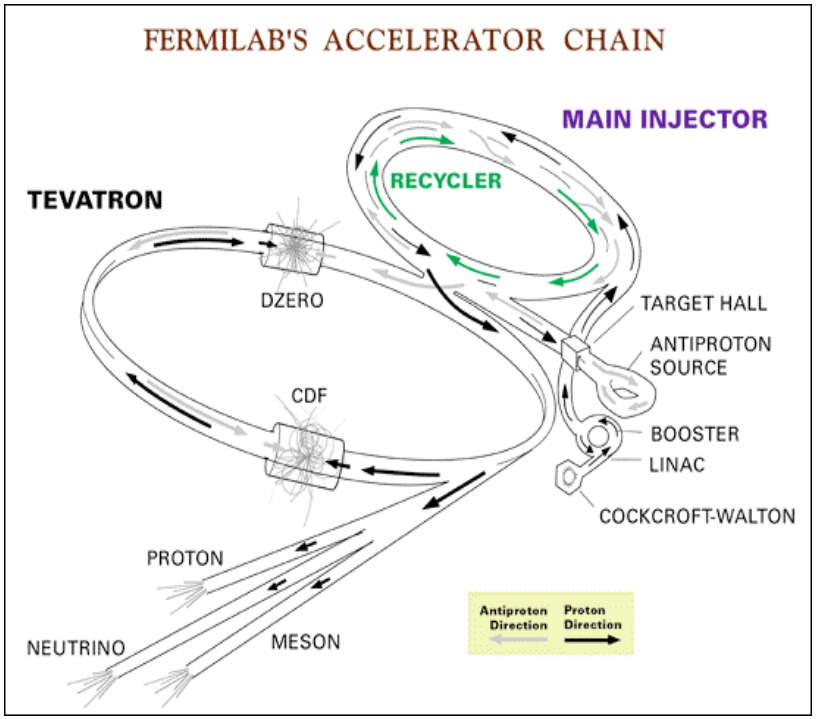
The Tevatron

Highest-energy accelerator currently operational

Peak luminosity → **3 *10^{32} cm^{-2} s^{-1}**
Integrated luminosity/week → **~ 25 pb^{-1}**

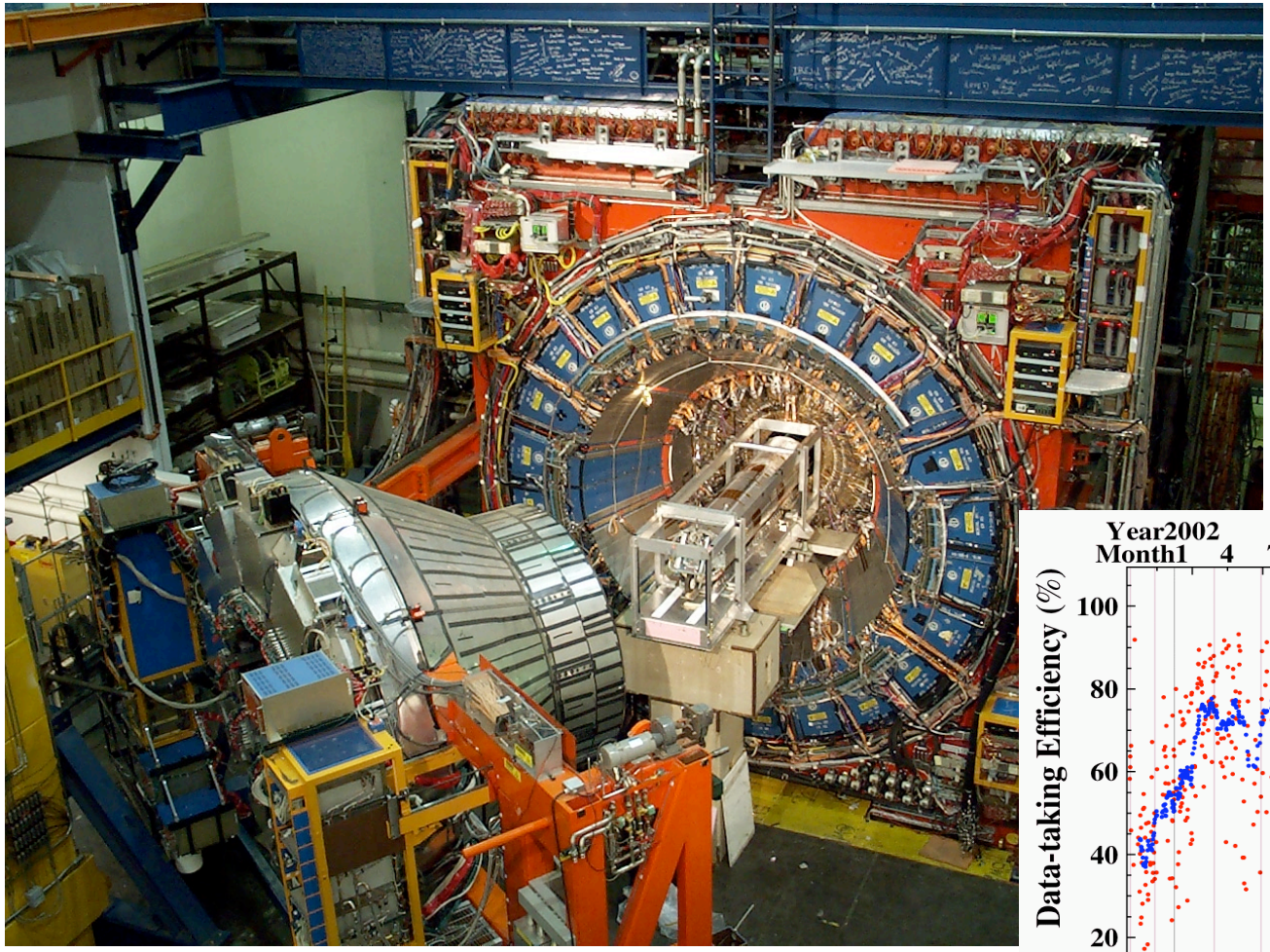
More than **2 fb^{-1}** recorded on tape for each experiment (CDF and D0)



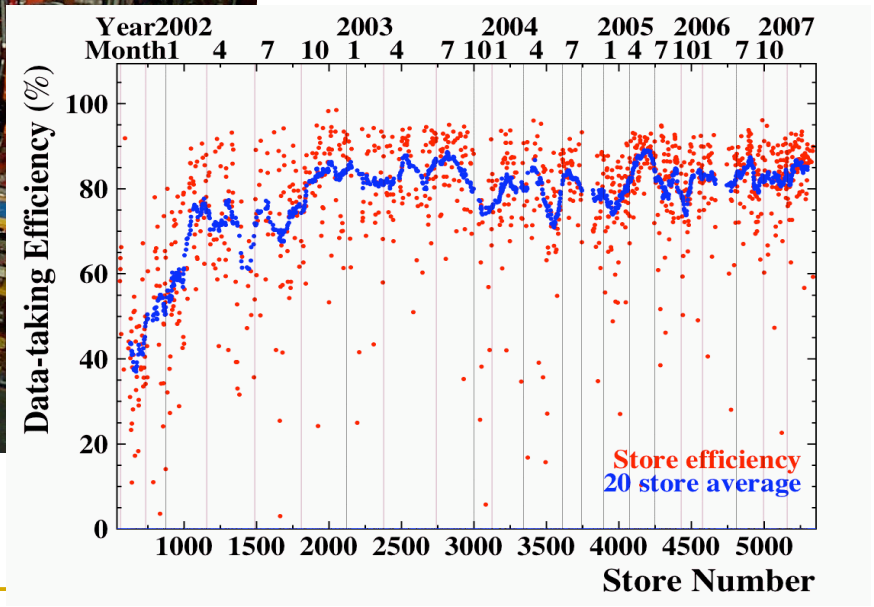


Analyses shown here use **0.3 – 1.1 fb^{-1}**

The CDF experiment

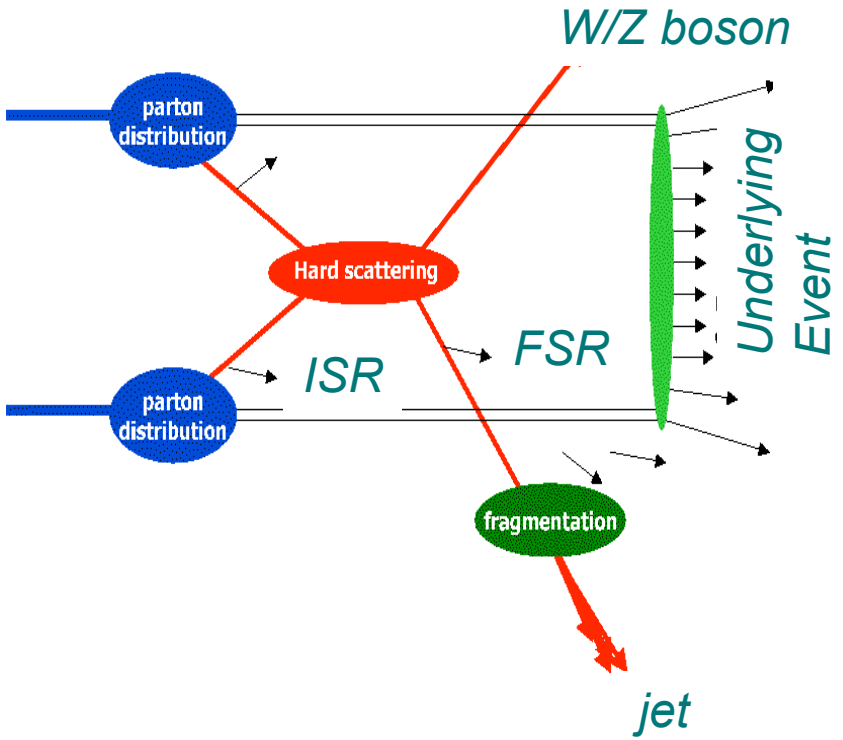


Recording data with high **efficiency (80-85%)** and making full use of detector capabilities.



Boson+jets at the Tevatron

- Test of pQCD in multijet environment:
  - high momentum transfers
  - NLO predictions available in some cases (MCFM)
- Sensitive to Underlying Event and Hadronization modeling

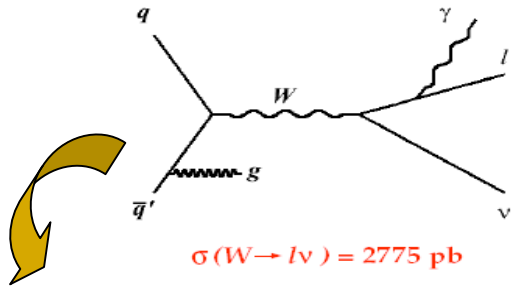


Fundamental processes to test **LO matrix elements** (ME) calculations **matched** with **parton showers** (PS):

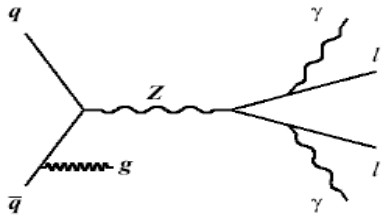
- Alpgen, Sherpa, MadGraph: ME + matching algorithms for parton shower (ckkw/MLM)

Inclusive W/Z

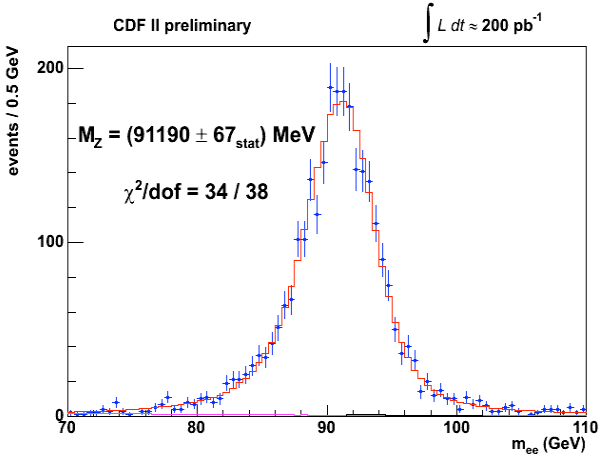
- Very accurate measurements of W and Z masses and inclusive cross sections

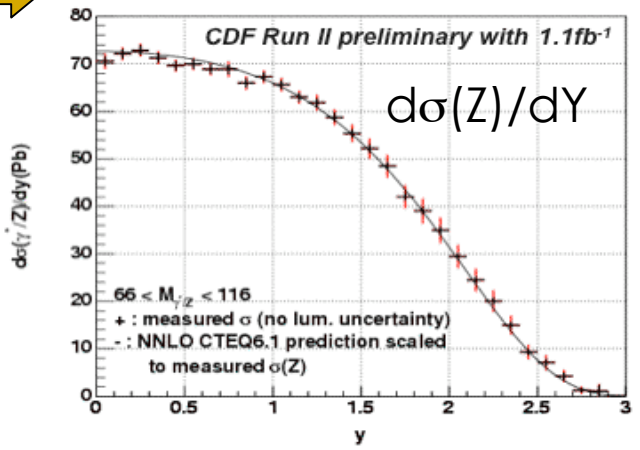


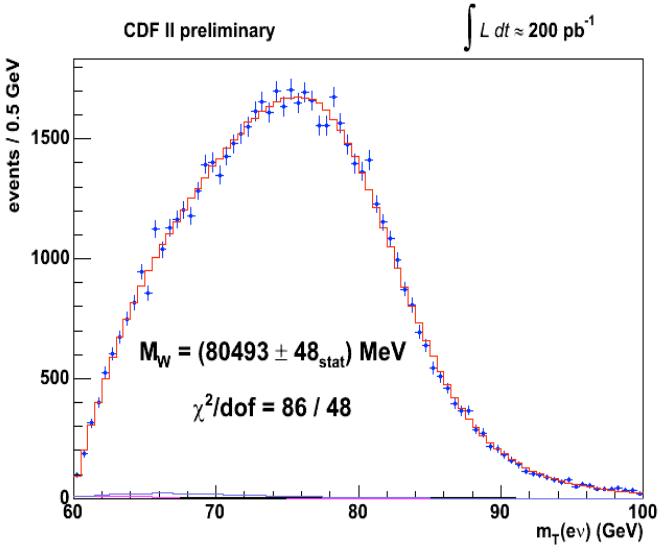
$\sigma(W \to l\nu) = 2775$ pb

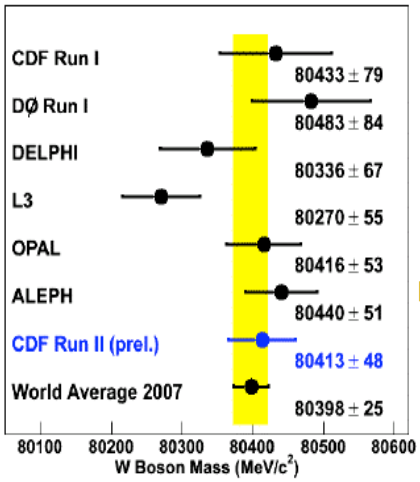


$\sigma(Z \to ll) = 254.9$ pb



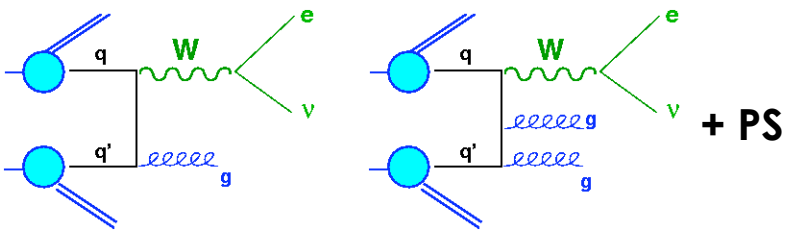






- Enough statistics to study jet production in association with W/Z in the final states

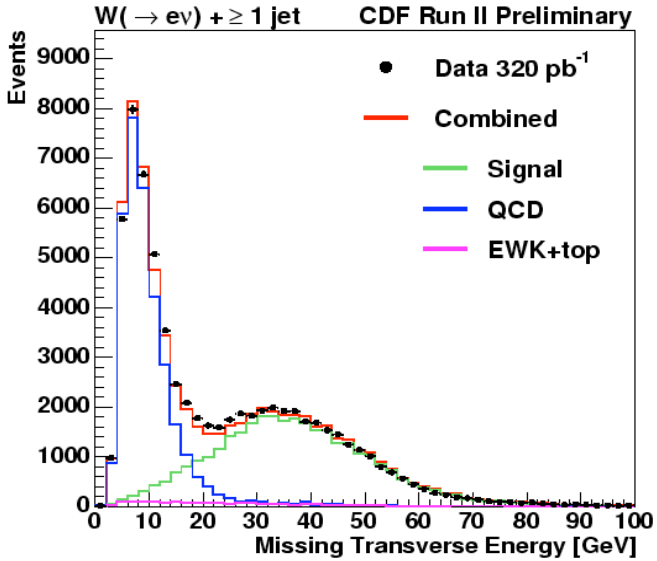
W(→ eν) + jets production

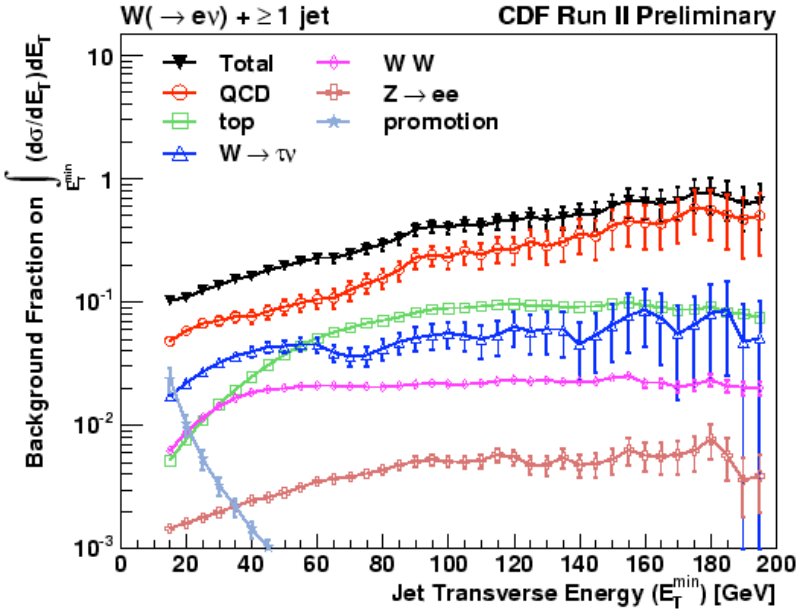


- E_T^{ele} > 20 GeV
- MET > 30 GeV
- m_T(W) > 20 GeV/c^2
- E_T(jet) >15 GeV , |η|<2.0, R=0.4
- ΔR(e,jet) > 0.52

Background:

- QCD (fake electrons)
- W→ τ ν , Z → ee, DiBoson , top

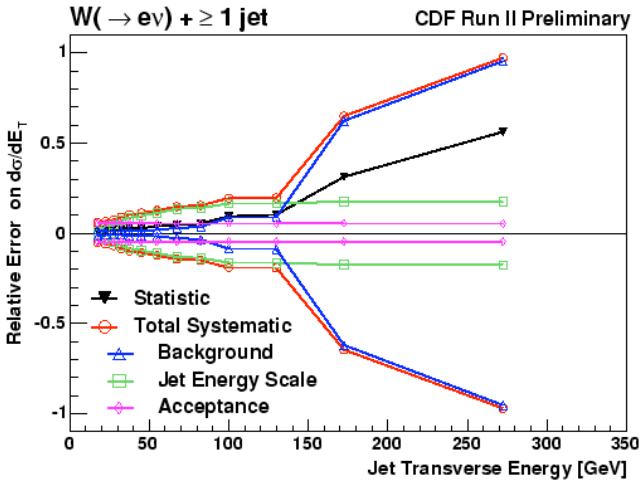


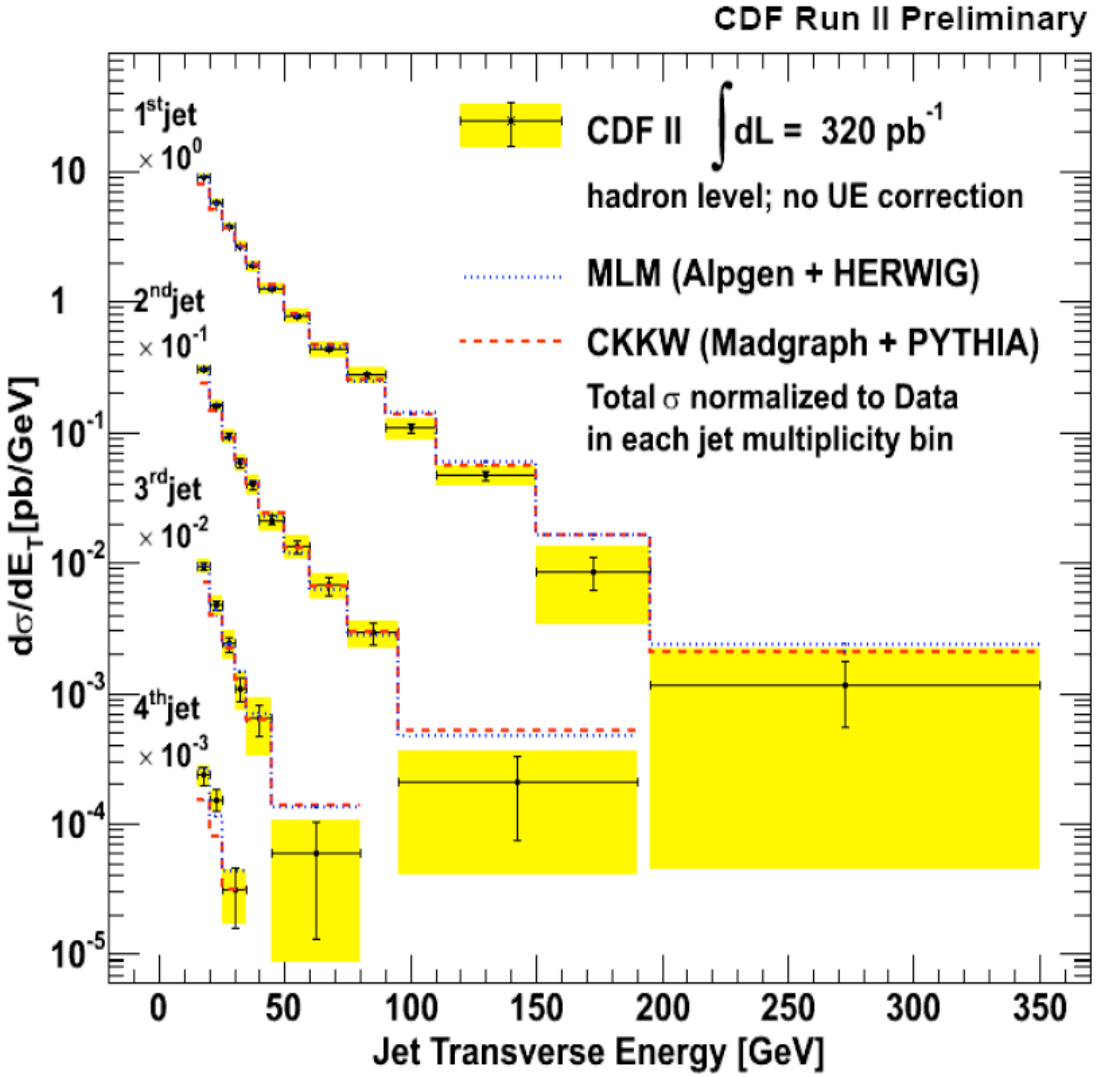


Differential cross section (E_T jets)

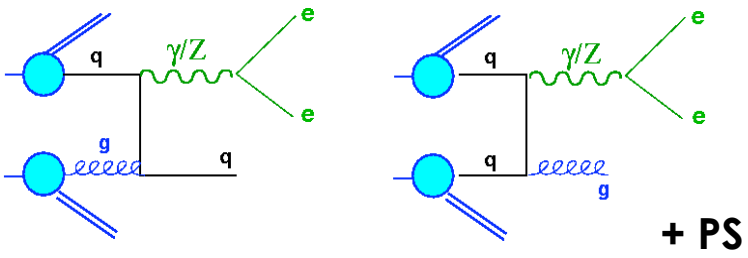
- ✓ Normalized to data
- ✓ Compared to different LO matrix elements + parton shower predictions with different matching techniques.

Systematic uncertainties dominated by Jet Energy Scale (JES) at low E_T, by background subtraction at high E_T





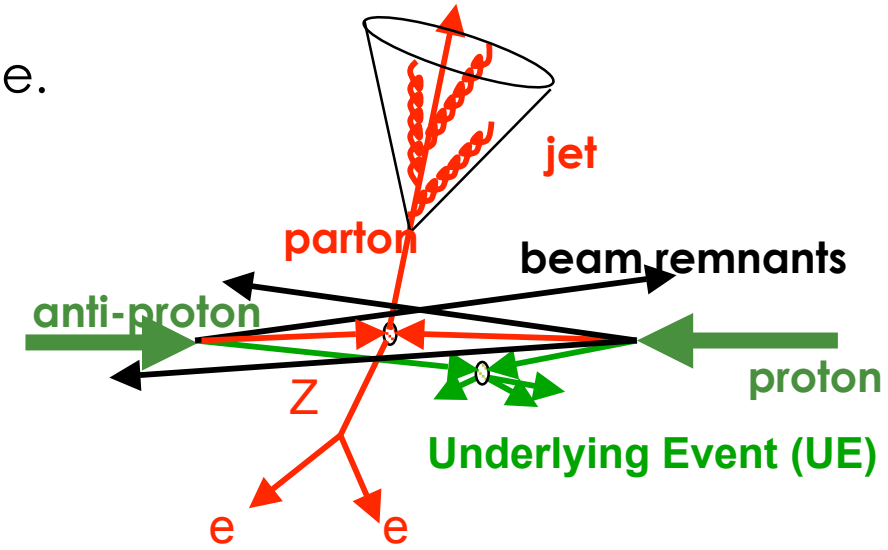
Z + jets production



+ PS

- Same good features:
  - Presence of a boson ensures high Q^2
  - Large BR into leptons

- No missing E_T: almost background free.
- Cross section is ~10 times less than W+jets, but with 1 fb^{-1} of data, enough statistics to make studies on Z+jets.
- Can be used to validate MC predictions without compromising searches for new physics



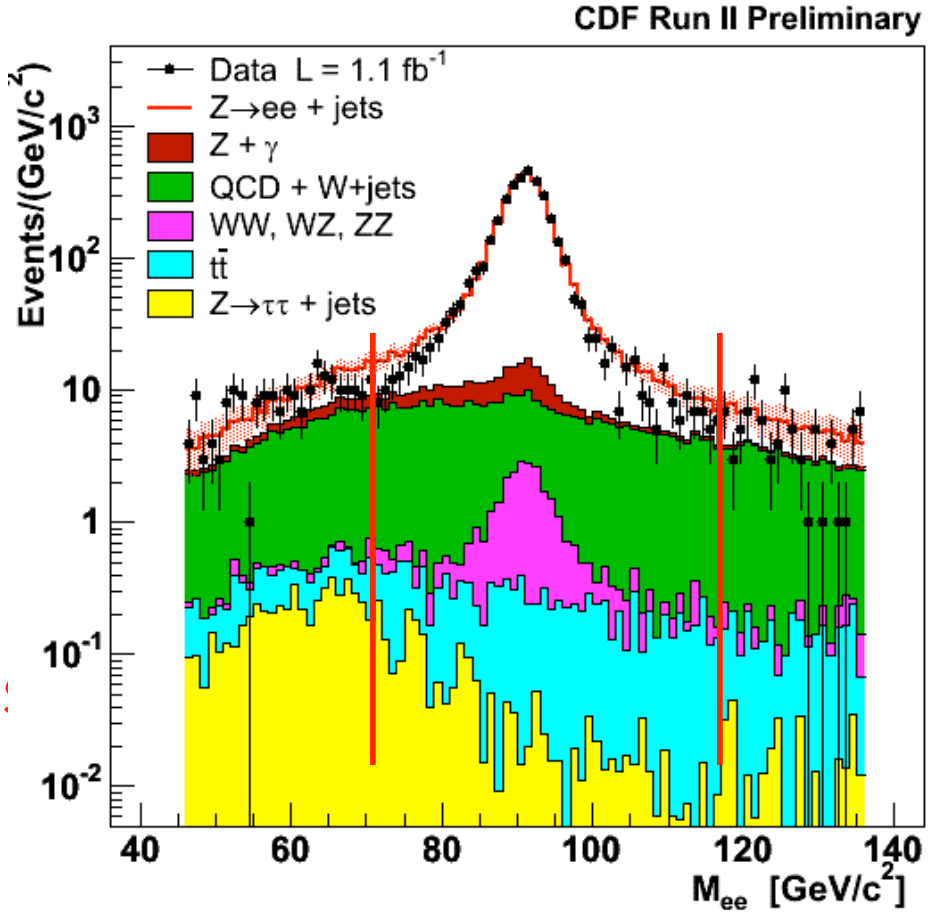
We will explore all different aspects of a typical hadron-hadron collision

Event selection and backgrounds

- Z selection
  - E_T(ele)>25 GeV
  - $|\eta|<1$ (central), $1.2<|\eta|<2.8$ (forward)
  - M_{ee} in [66-116] GeV/c^2:
- Jet selection:
  - MidPoint R = 0.7
  - $p_T^{corr} > 30$ GeV/c, $|Y| < 2.1$
  - ΔR(e,jet) > 0.7
- Cross sections measured a
a function of jet P_T and jet Y

Main background:

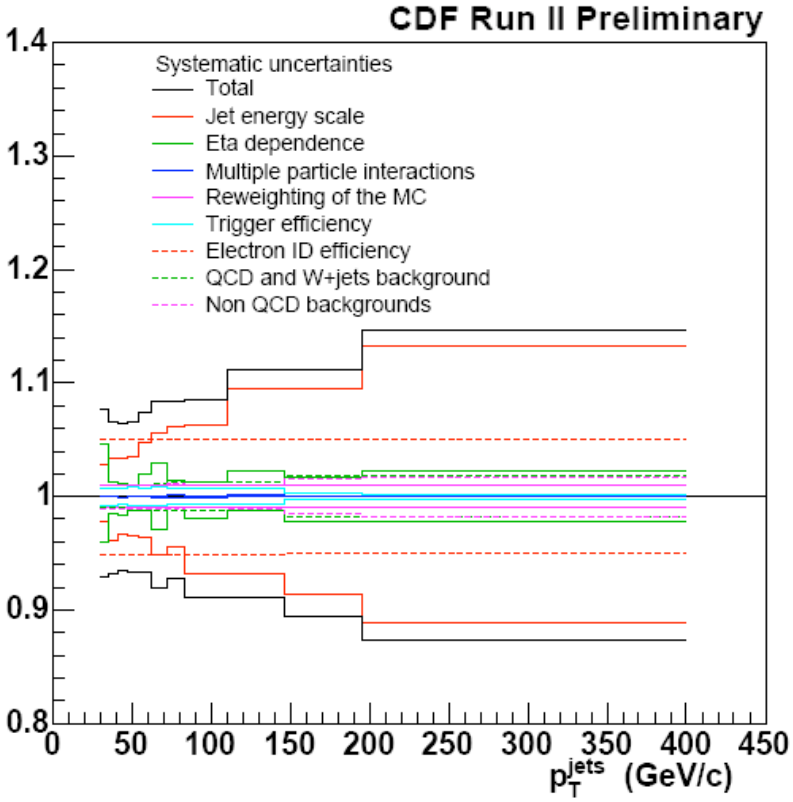
QCD and W+jets (~ 5-10%)

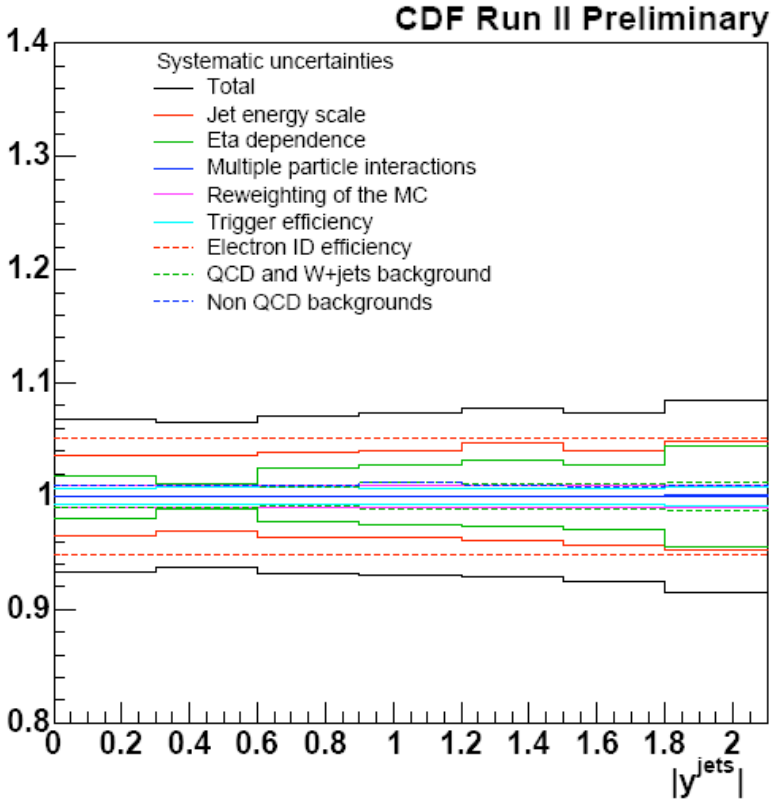


Other backgrounds as ttbar, Zγ, Z→ττ+jets contributing for < 1%

Total Systematic Uncertainty

- Dominated by the **jet energy scale** uncertainty
- Total systematic uncertainties between **8%** and **15%** in p_T^{jet}
- Flat in rapidity : **~ 8%**

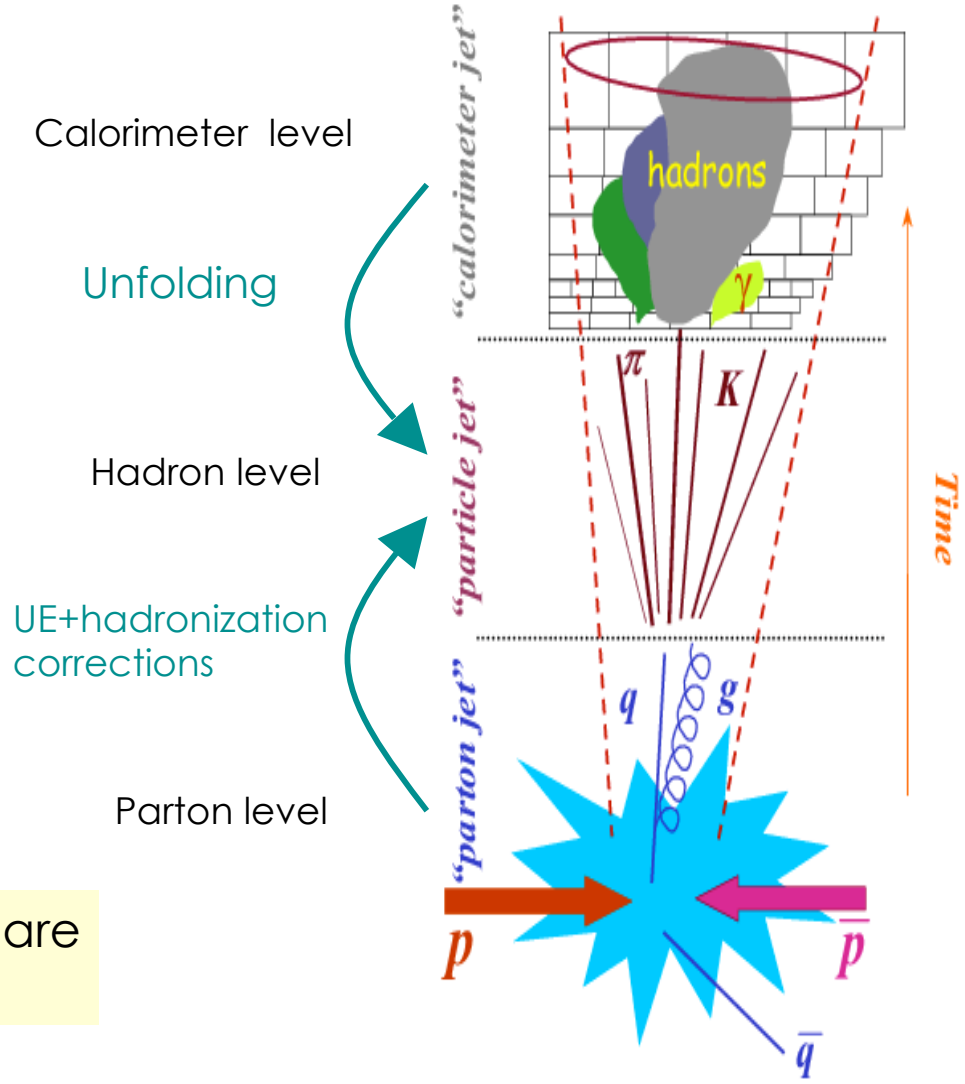




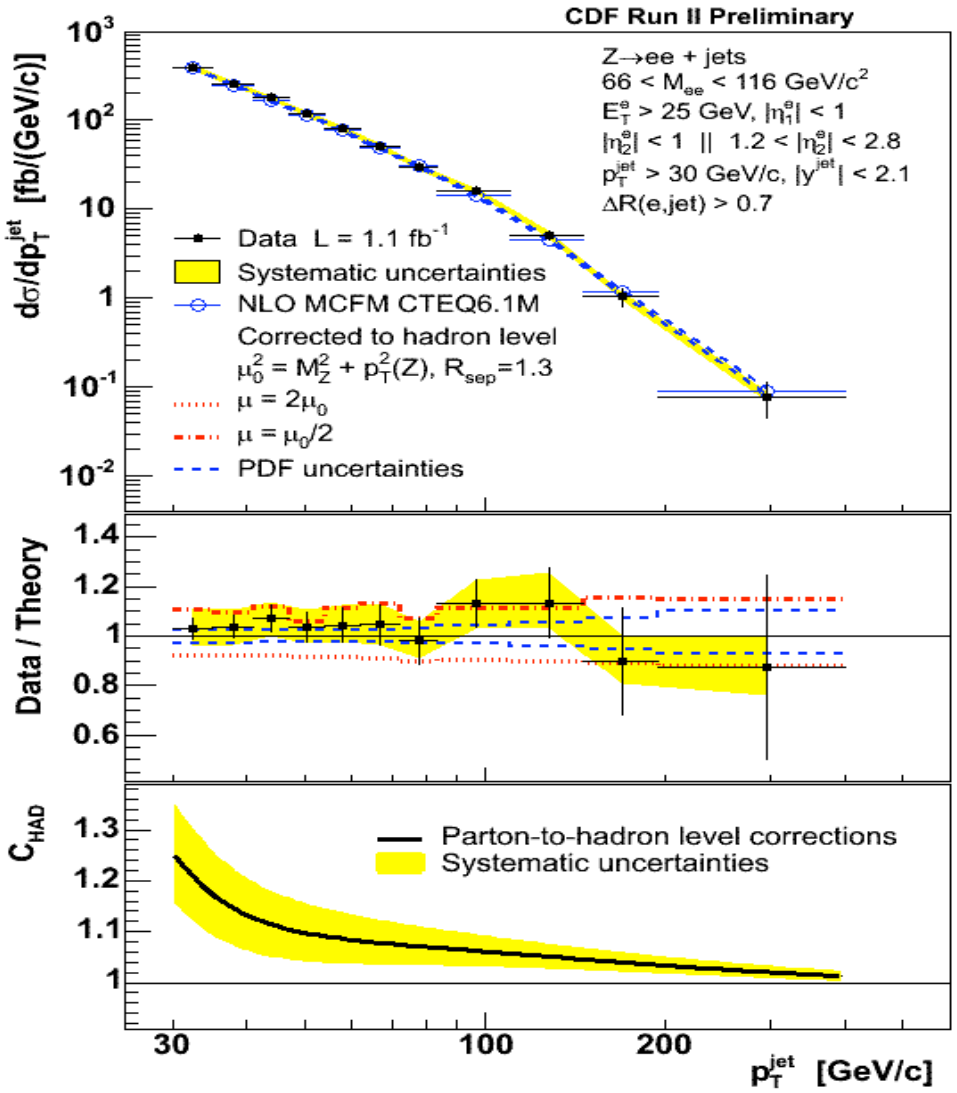
NLO pQCD prediction

- MCFM
  - NLO predictions up to 2 jets in final state
  - CTEQ6.1M PDF
  - Renormalization and factorization scale:
    $\mu_0 = M_Z^2 + p_T^2(Z)$
  - Jets reconstructed using MidPoint algorithm with R_{sep} = 1.3
  - Cross section at parton level:
    - needs correction for UE and hadronization effects

→ Corrections for non-pQCD effects are made using Monte Carlo

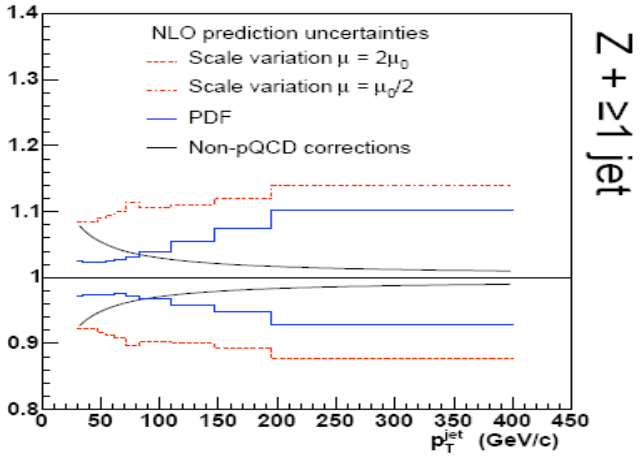


Cross Section Z+ ≥ 1 jet



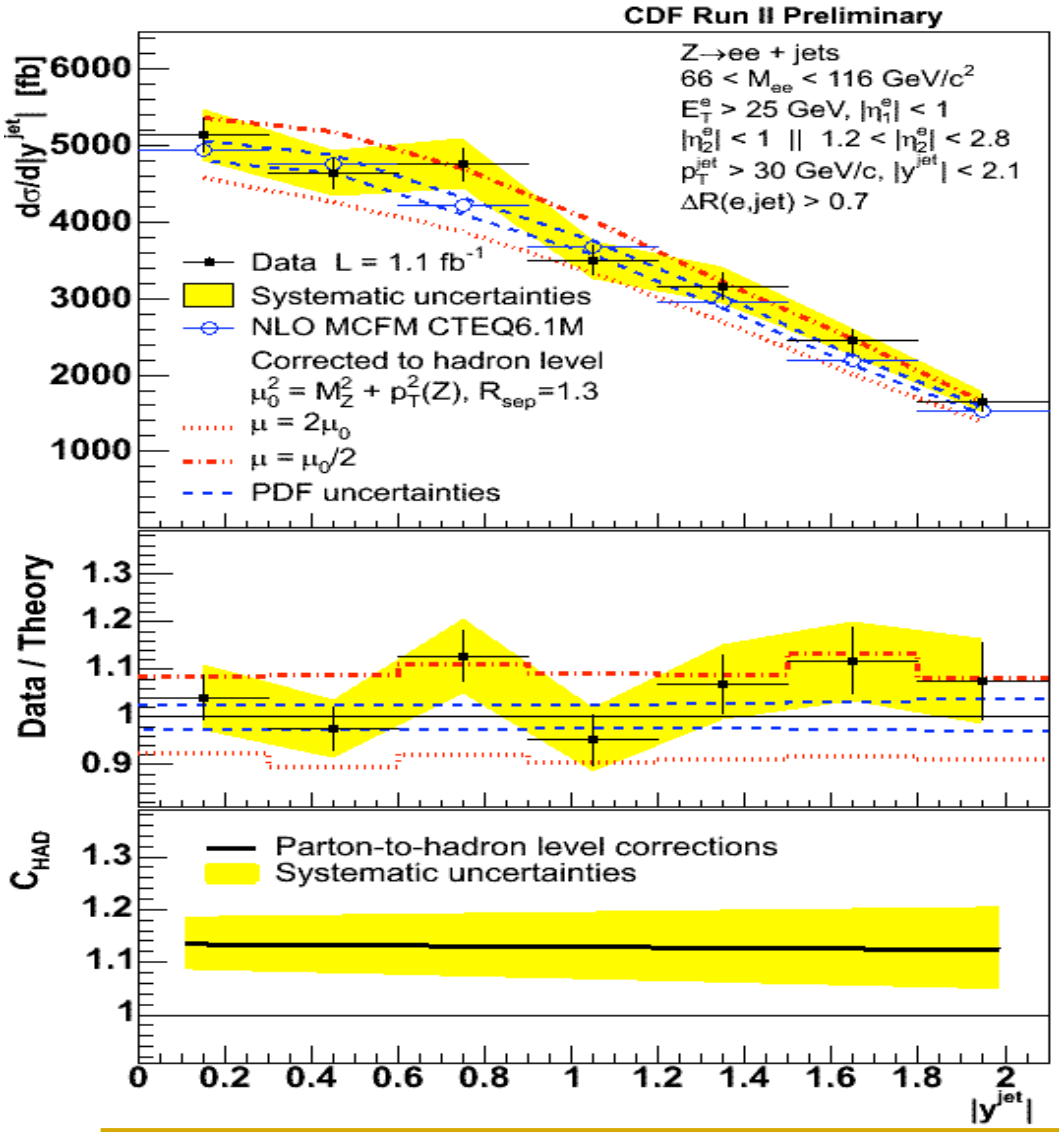
Uncertainties on theoretical calculation:

- PDF uncertainties:
  - using Hessian method: 3-10%
- Renormalization and factorization scale variation (run at $2\mu_0$ and $1/2\mu_0$):
  - 10-15% variation in the prediction
- Uncertainties on non-pQCD factors:
  - Up to 8% at low p_T jet



Good agreement between data and NLO pQCD

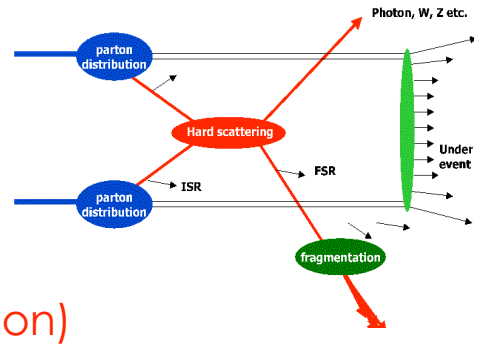
Cross Section vs Y(jets)



- Z+≥1 jet
- Data corrected to hadron level.
- Good agreement with NLO predictions with non-perturbative contributions
- A number of measurements are performed to validate our modeling of the Underlying Event and fragmentation

Underlying Events in Z+jets

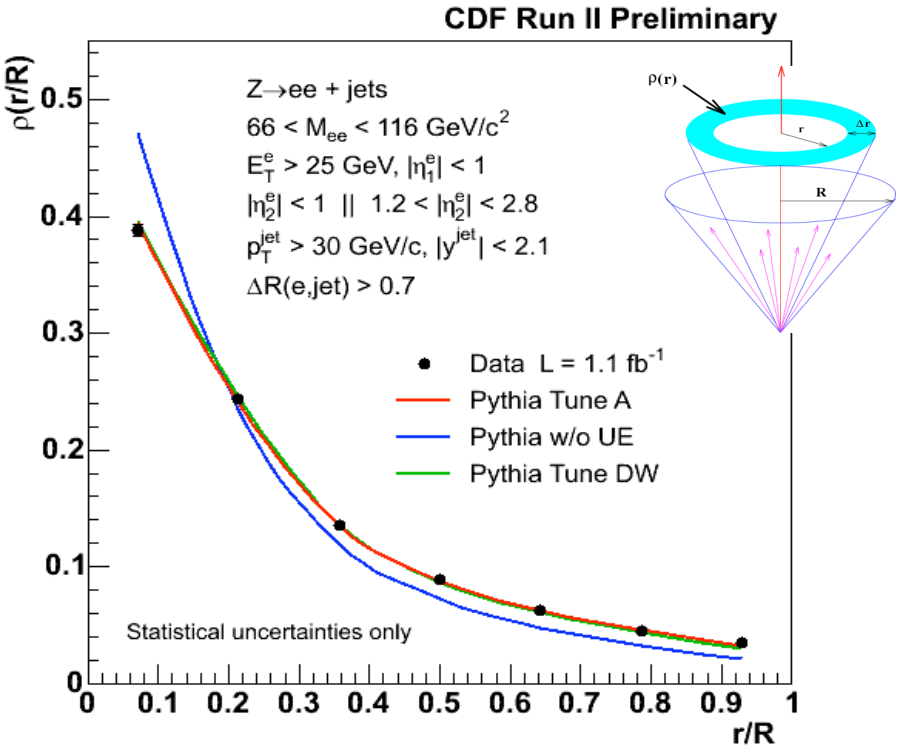
Jet shapes

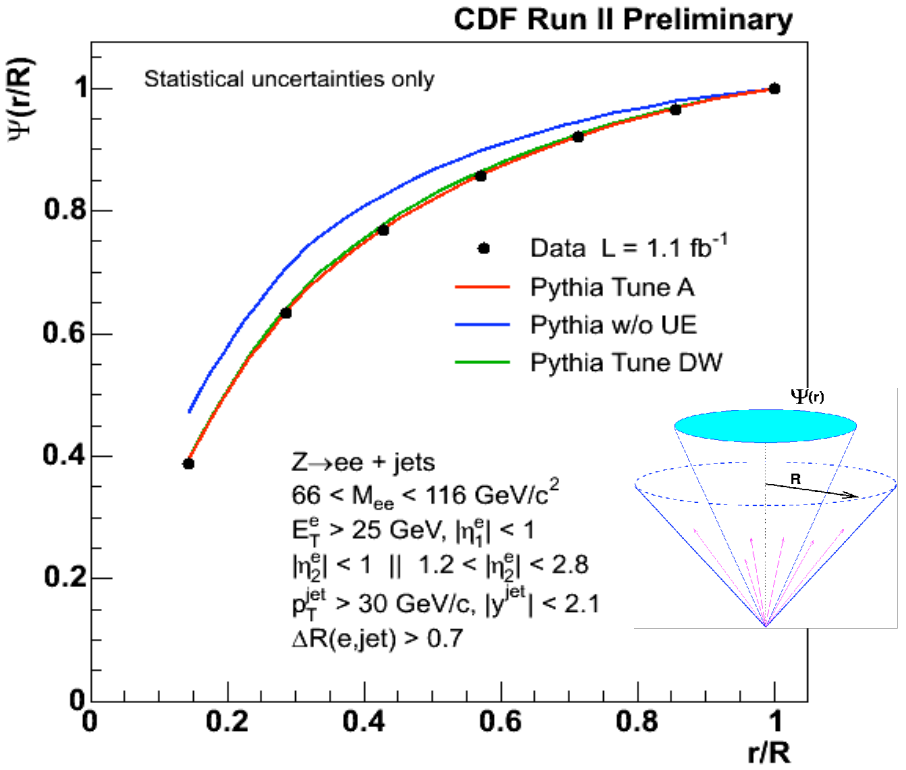


sensitive to **fragmentation** and **underlying event** modeling.

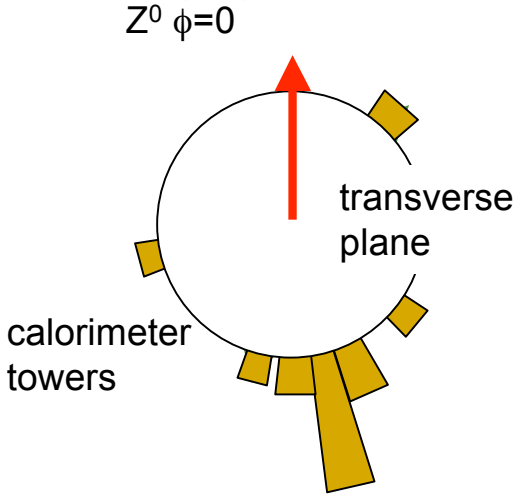
→ very accurately described by Pythia Tune A

(same that also describes the jet shapes in inclusive jet production)

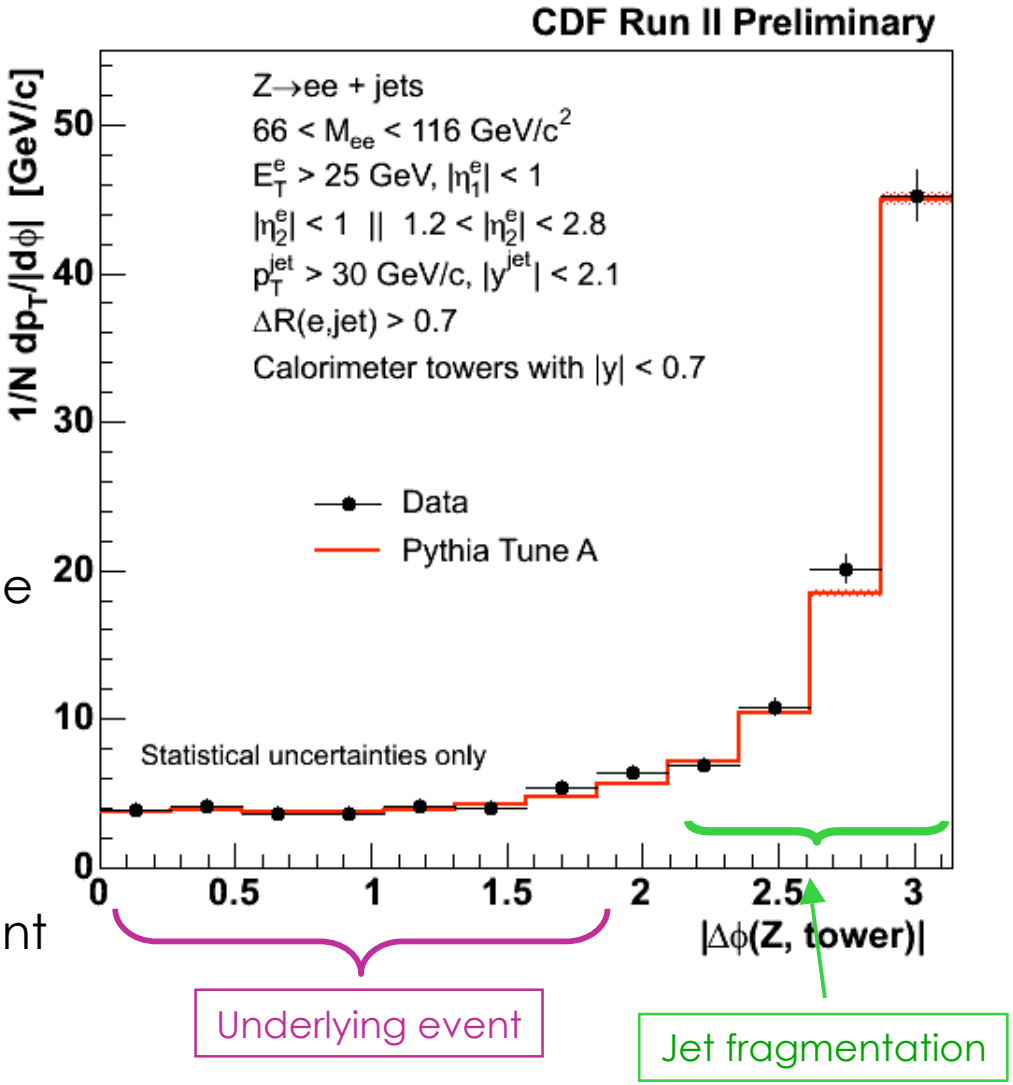




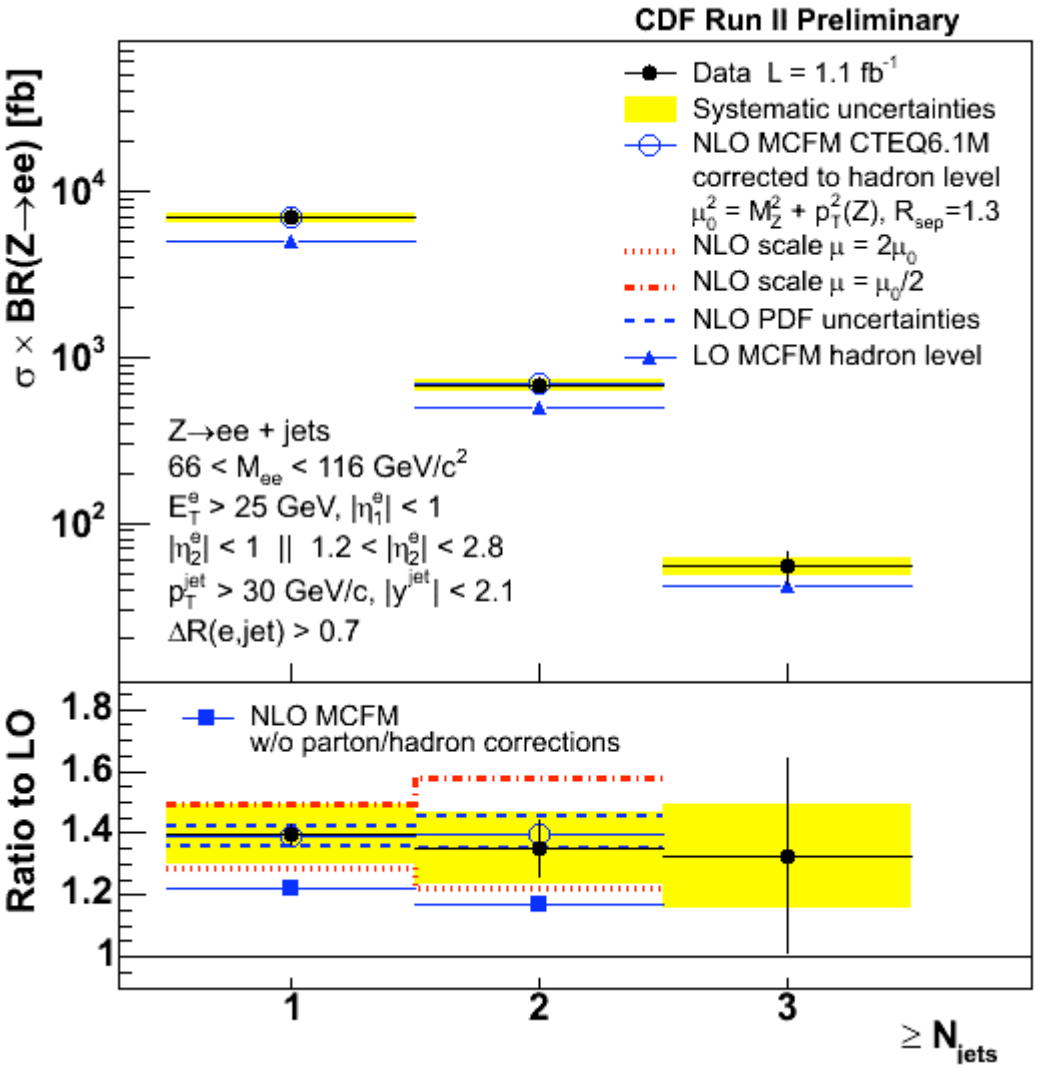
Energy flow



- p_T flow of particles in the transverse plane w.r.t the Z Boson
- Jet is described very accurately
- Very good agreement in the part dominated by the underlying event



Jet Multiplicity



Cross Section w.r.t. the number of jets (inclusive)

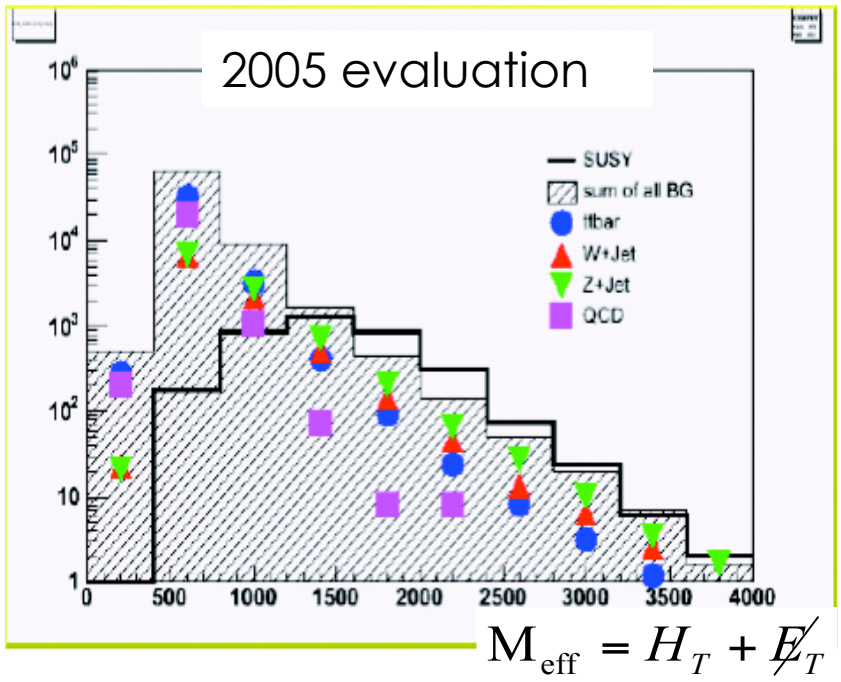
- Good agreement between data and NLO pQCD.
- ±10% uncertainty from renormalization and factorization scale (factor 2 and ½ variation)
- k-factor (NLO/LO) is rather flat and around ~1.4
- ~ 15% more jets due to the non-pQCD effects.

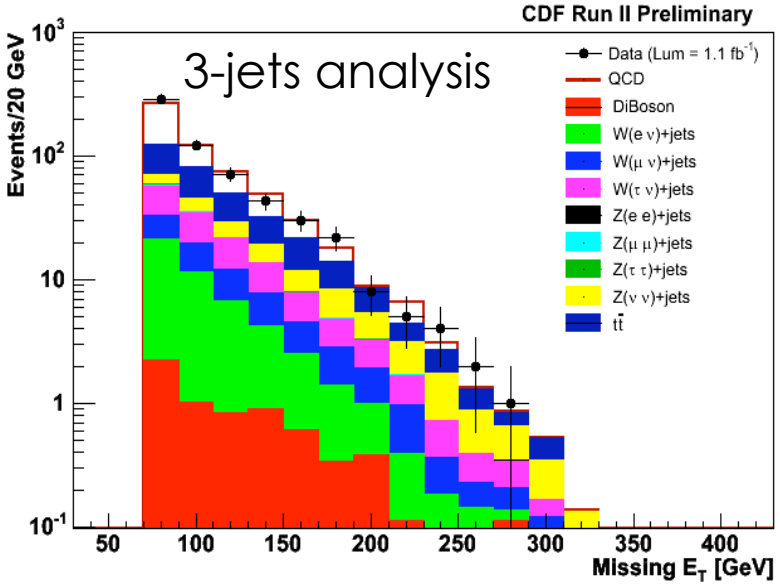
Boson+jets as bkg. for new Physics

- Important backgrounds to
  - top production, Higgs searches
  - SUSY searches → **an example**

Squark/gluino pair production in mSUGRA scenario (R-parity conservation)

Signature: energetic jets + Missing transverse Energy (undetected LSP)





Preliminary MC studies (1999) at the LHC suggested that SUSY could be discovered via the jet+MET channel within weeks after LHC started → Since then, many changes in tools used for background

Summary

- Tevatron and CDF experiment performing well:
  - > 2 fb^{-1} data on tape (~ 80-85% efficiency)
- Boson+jets are fundamental to test pQCD, underlying Event and new LO ME calculations + Parton Shower Monte Carlo generators.
- Measurements on W+jets and Z+jets production shown.
  - W+jets cross section:
    - compared to ME+PS Monte Carlo
  - Z+jets cross section:
    - Compared to NLO pQCD calculations.
    - p_T , Y and Jet multiplicity distributions in inclusive Z+jets production.
    - Non-pQCD corrections are sizeable (~15% more jets).
- Important background for top, Higgs and SUSY searches


Back up

Jet reconstruction

Final state partons are revealed through collimated flows of hadrons called **jets**

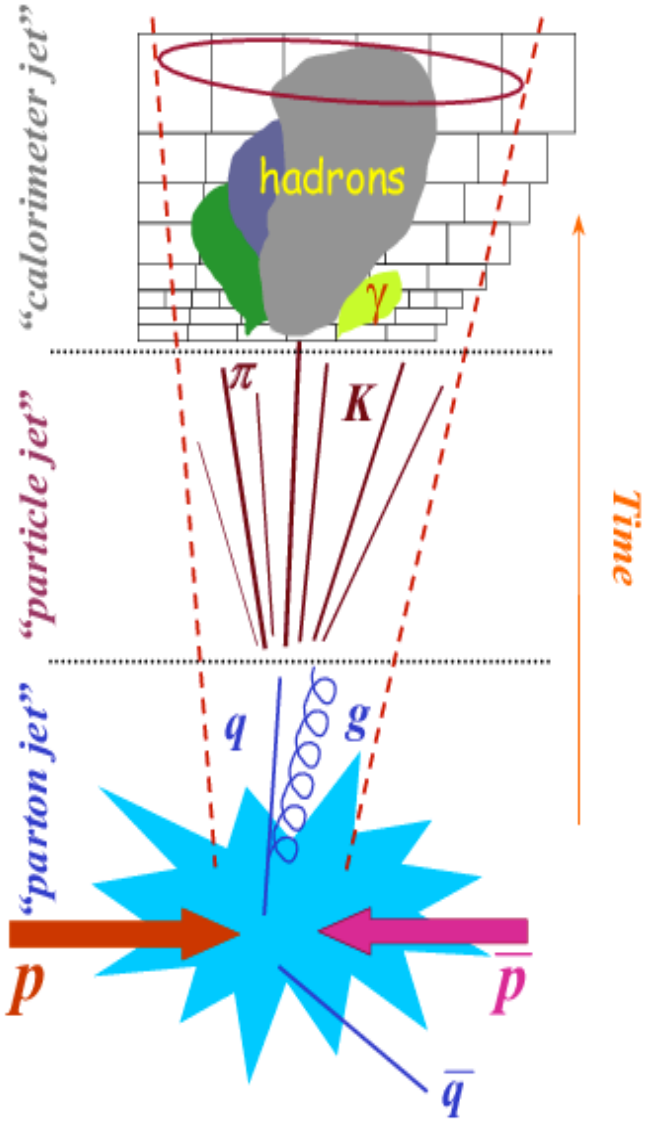
Measurements → at hadron level
Theory prediction → parton level_

Need to have common and unambiguous definition used for theory and experiments.

→ **Jet reconstruction algorithms:**

- infrared and collinear safe
- jet direction = parent parton direction

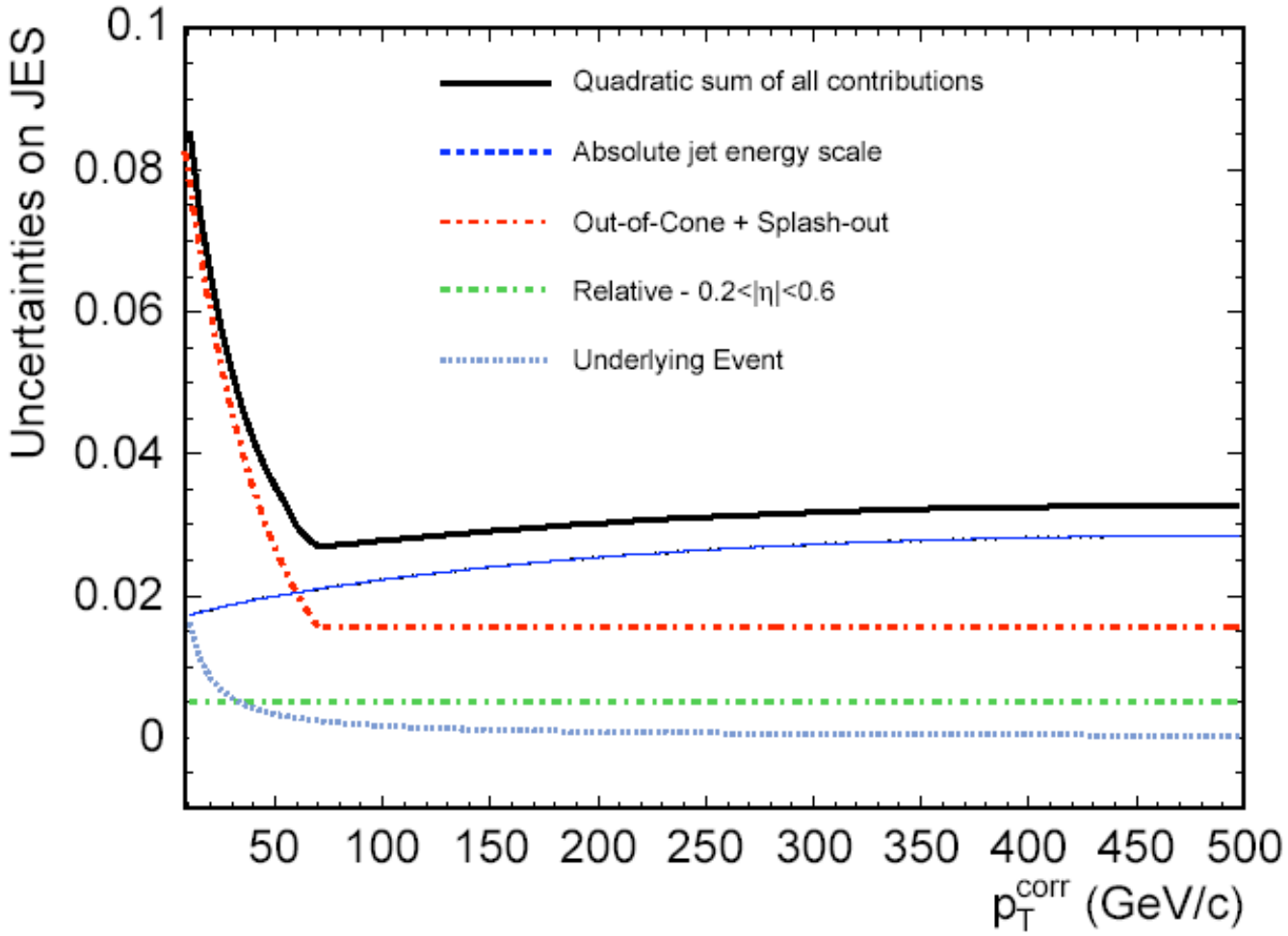
Two main types of jet algorithms:
- Cone Algorithm
  → JETCLU (Run I like) and MIDPOINT
- K_T algorithm



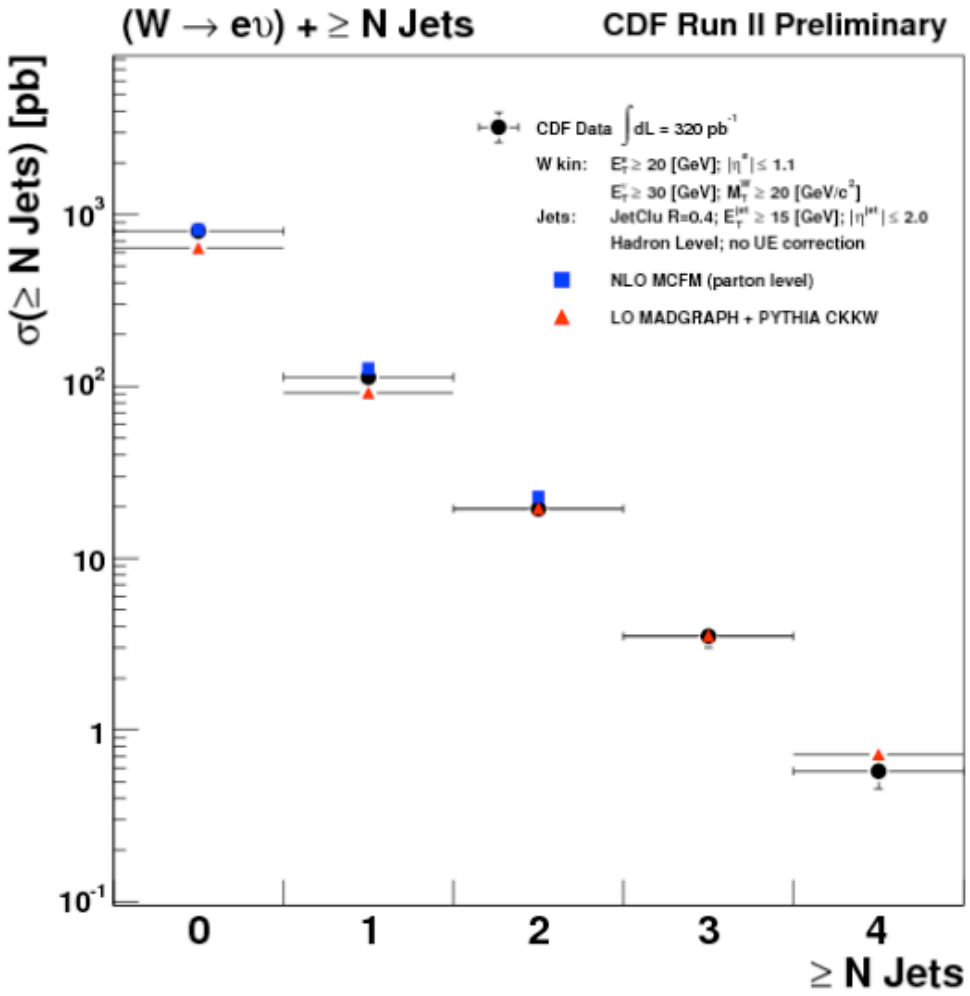
JES Systematic uncertainties

Total systematic uncertainties for JES

→ between 2 and 3% as a function of corrected transverse jet momentum



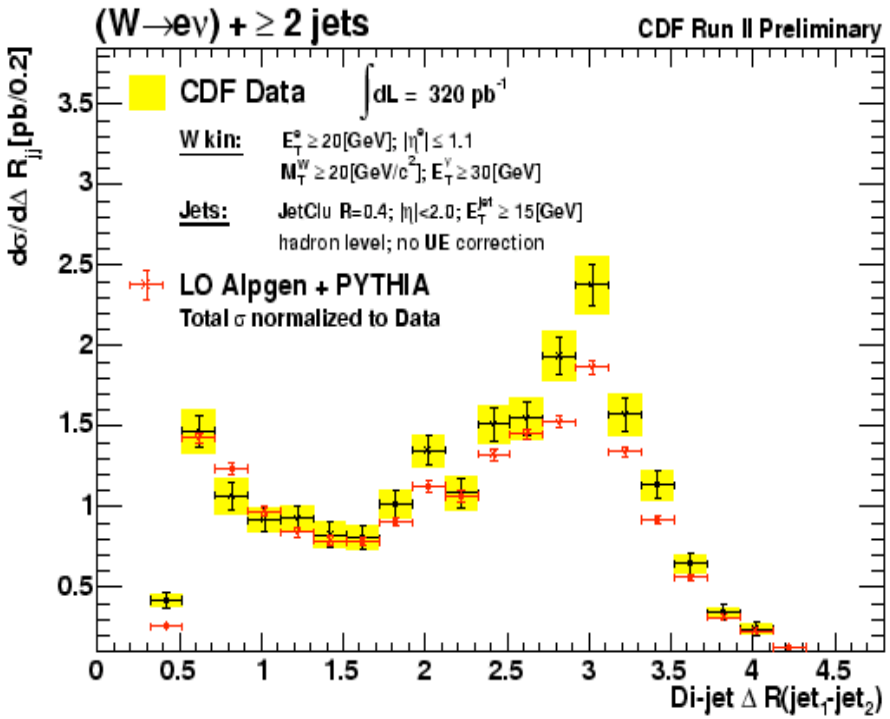
W (→ eν) + jets



- Jet Multiplicity
  - hadron level cross section

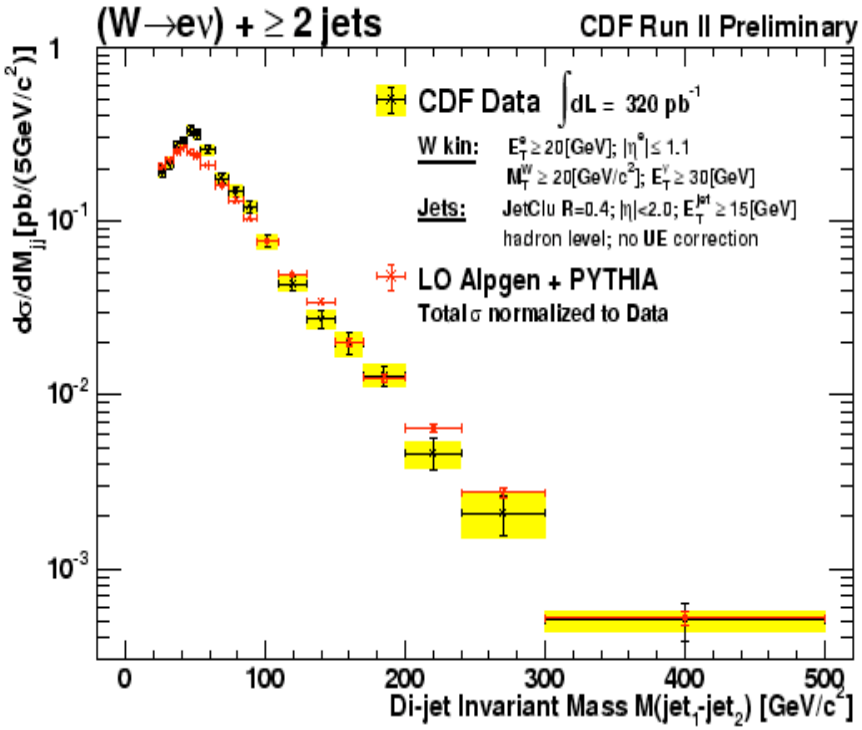
- Ongoing comparison to:
  - NLO prediction
    - at parton level
    - no parton to hadron corrections applied.
  - LO matrix elements

Jet correlations



Differential cross section w.r.t. di-jet ΔR in the W+2 jet inclusive sample

Differential cross section w.r.t. di-jet invariant mass in the W+2 jet inclusive sample



LO predictions normalized to data integrated cross sections

→ **Shape comparison only**